# CFD Modeling of FCC Riser Reactor

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**ABSTRACT-** In the present work a two phase flow FCC riser model incorporating a four lump kinetic scheme is presented. The two-phase flow (gas-solid) in the riser is modeled using the Eulerian- Eulerian multiphase flow model. The model simulation studies are presented using two cases: gas-solid flow without reaction, and gas-solid flow with reaction. The results for the two phase flow without reaction show that the gas phase velocity decreases along the riser height as the gas loses momentum. The catalyst velocity increases as the catalyst gains momentum. The temperature of the gas phase increases as it gains heat from the hot catalyst; and the catalyst temperature decreases. The results for gas-solid flow with reaction predict the gas phase velocity increase from 4.7 to 14.7 from riser inlet to outlet due to cracking of heavy gas oil to lighter products. The model predicted gas oil conversion 62%, gasoline yield 39%, light gases yield 20%, and coke yield 3%.

***Keywords:*** Fluid catalytic cracking, riser model, CFD model, Riser temperature, Gas phase velocity

## 1. INTRODUCTION

FCC units are used widely in refineries to produce higher value gasoline from gas oil.FCC units mainly consists of two basic units, a reactor in which the hot catalyst is brought in contact with the feed (gas oil), and a regenerator in which the coke deposited on the catalyst is burned off for regenerating the catalyst. Riser is most important part of FCC unit from modeling viewpoint.

The conversion of heavy petroleum fractions to the products takes place in the riser reactor, which is a long tube of length (30-40m) with a proportionally smaller diameter (0.8-1.2m). After complete vaporization of hydrocarbon feed, two phases solid phase(catalyst), gas phase (hydrocarbon vapor and steam) are left in the riser. Catalytic reactions occur in the vapor phase. The expanding volumes of the vapors that are generated are the main driving force to carry the catalyst up the riser. Catalyst and products are quickly separated in the reactor. The various aspects of the FCC riser modeling are reaction kinetics, hydrodynamics, heat and mass transfer and catalyst deactivation. Gupta et al. (2005, 2010) have reviewed the FCC riser modeling efforts of various authors.

CFD is emerging as a powerful tool for modeling the FCC riser. In recent decades, with the advancement of computational techniques and computer hardware, CFD is being increasingly used to simulate gas–solid fluidized beds. The majority of the research groups have used Eulerian–Eulerian approach, where the dispersed solid particles are treated as an interpenetrating continuum. The kinetic theory of the granular flow is used to simulate gas–solid flow in the riser. Most of the works on the FCC riser reactor have focused on either reactor hydrodynamics or catalytic cracking kinetics. Many theoretical and experimental studies are carried out to better understand the complex hydrodynamics of gas–solid turbulent flow in the reactor (Gao et al., 1999; Huilin et al., 2003; Jiradilok et al., 2006; Wang et al., 2008; Wang et al., 2010). Huilin et al. (2005) used a cluster-based approach and predicted the hydrodynamics of cluster flow in circulating fluidized beds. Authors showed a considerable improvement in the model predictions using cluster-based approach as compared to the model based on original kinetic theory of granular flow. Jiradilok et al. (2006) proposed the turbulent fluidization of FCC particles in a riser.

Shuyan (2008) proposed a mathematical model for predicting gas and gasoline distributions in the cluster by coupling a hydrodynamics model with four-lump catalyst cracking reactions. Lu et al. (2008) presented a gas-solid multi-fluid model with two granular temperatures of the dispersed particles and the clusters in risers, to predict the hydrodynamics of dispersed particles and clusters flow in CFBs. In addition to the basic governing equations developed from the universal laws, it is necessary to develop relevant constitutive equations and equations of state for the fluids under consideration to close the system of equations. Several closure models have been proposed to define the appropriate constitutive equations for binary or multi-phase flows based on the kinetic theory of granular flow. The constitutive equations are needed to close the solid phase momentum.

Behjat et al. (2010) proposed a 3-D FCC riser reactor model, which takes into account the hydrodynamics, heat transfer and evaporation of the liquid gas oil injected into the gas–solid fluidized bed. Lopez et al. (2011) developed a model of three-dimensional and two-phase flow model to predict the dynamic behavior of a fluid catalytic cracking (FCC) industrial reactor.

In the present work, FCC riser is simulated using Eulerian-Eulerian approach. The vaporization of feed is assumed to be instantaneous. The heat transfer mechanism is described using Ranz-Marshal correlation. Widely used four lump kinetic scheme is used to predict the product's yields. This four lump kinetic scheme, is used by several investigators (Ali and Rohani, 1997; Blasetti et al., 1997; Gupta and SubbaRao, 2001; Nayak et al., 2005; Lopez et al., 2011).

## 2. FCC RISER MODEL

The two-phase flow model uses Eulerian description of both phases, so the gases and the dispersed solid particles are treated as interpenetrating continuum. In the present work, Syamlal-O'Brien drag model (1989) is used.The heat transfer between phases plays an important role in the catalytic cracking of the hydrocarbons. The gas and solid energy equations are used with Ranz–Marshall correlation for single particle for the estimation of Nusselt number. A four lump kinetic scheme is used due to its simplicity.The general rate equation for reaction $r$(kmol/m$^3$.s)is given by:

$$R_{i,r} = k_r C_i^n$$

where, $k_r$ is rate constant for $r^{th}$ cracking reaction, $C_i$ is concentration of $i^{th}$ species (kmol/m$^3$).The values of kinetic parameters used in the model are reported in Table1.

Plant data reported in Table 2 is used for the simulation. The gas oil feed is assumed to vaporize instantaneously at the riser inlet. The temperature of vaporized feed at the inlet is taken as 700 K and temperature of the catalyst is taken as 860 K. Theinlet gas phase velocity at 4.74m/s and catalyst phase velocity is 0.295m/s.

**Table-1:** Kinetic parametersforthe four-lump model

| Reaction | Pre-exponential factor ($m^3 / m^3_{cat}$.s) | Activation energyE, (kJ/kmol) |
|---|---|---|
| Gasoil (VGO) to Gasoline | 0.06 | 68316 |
| Gasoil (VGO) to Light Gases | 0.04 | 89303 |
| Gasoil (VGO) to Coke | 0.0076 | 64638 |
| Gasoline to Light Gases | 0.0042 | 52768 |
| Gasoline to Coke | 0 | 115566 |

**Table-2:** Plant Data (Ali and Rohani, 1997)

| Parameter | Value |
|---|---|
| Feed flow rate | 20 kg/s |
| Catalyst flow rate | 144 kg/s |
| Riser Diameter | 0.8 m |
| Riser Pressure | 2.9 atm |
| Riser height | 33 m |

## RESULTS AND DISCUSSION

The gas-oil feed is assumed to be instantaneously converting into vapor after contacting with the hot catalyst coming from the regenerator. Due to the cracking reactions, the density of the gas phase decreases which results in the increase in gas phase velocity. Though, the catalyst is being dragged by the gas there is net increase in gas velocity due to cracking. It can be seen from the contour of velocity magnitude of gas phase (Figure 1) that the velocity keeps on increasing all along the riser height. The feed vapor drags catalyst particles up the riser and there is increase in the velocity of the catalyst along the riser height(Figure 2).

The heat is transferred from catalyst phase to gas phase. The temperature of gas phase (Figure3) increases due to heat gain, and catalyst temperature (Figure4) decreases due to heat loss. The yield is expressed in terms of weight percent. Yields of various products are presented in Table 3. The predicted gas-oil conversion is 62%. The contour plot of gas-oil mass fraction along the riser is shown in Figure5.

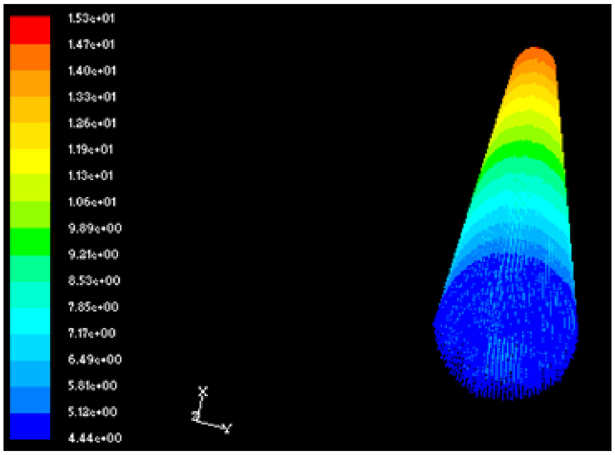


**Fig-1**: Gas phase velocity along the riser height

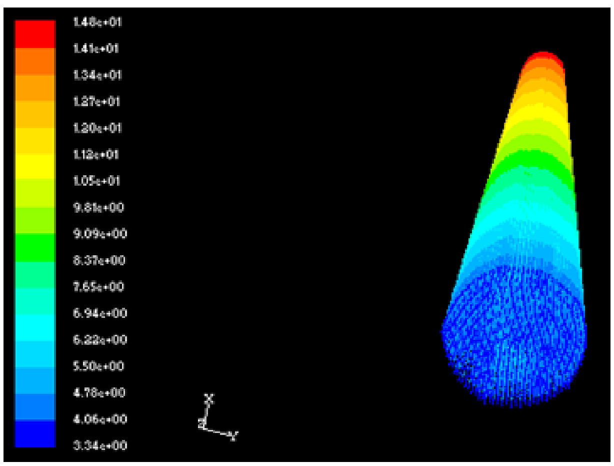


**Fig-2**: Catalyst velocity along the riser height

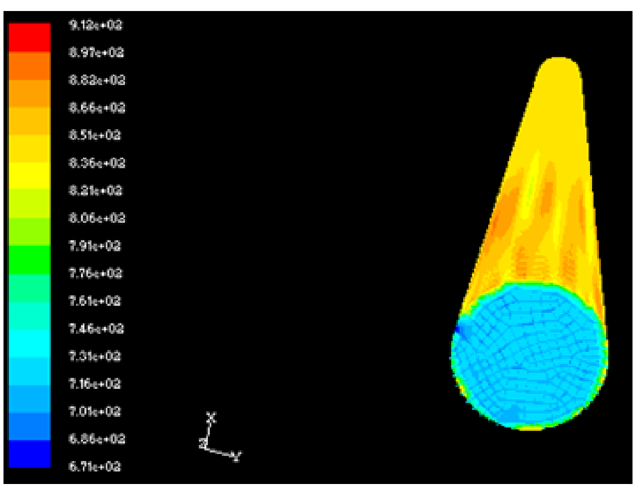


**Fig-3:** Gas phase temperature along the riser height

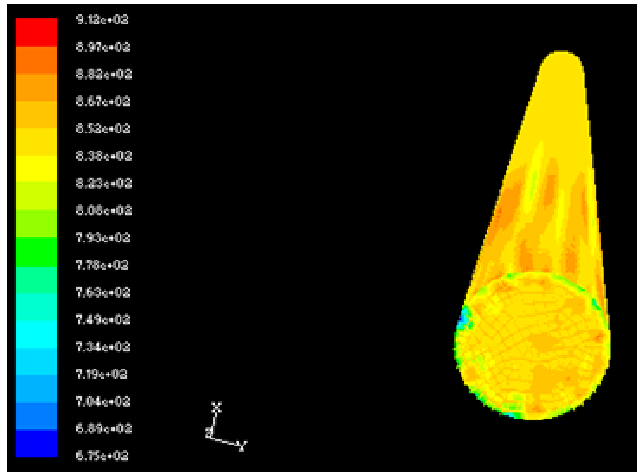


**Fig-4**: Catalyst temperature along the riser height

**Table-3:** Product Yields

| Product | Product yield (wt %) |
|---|---|
| Gasoline | 39 |
| Light –gases | 20 |
| Coke | 3 |

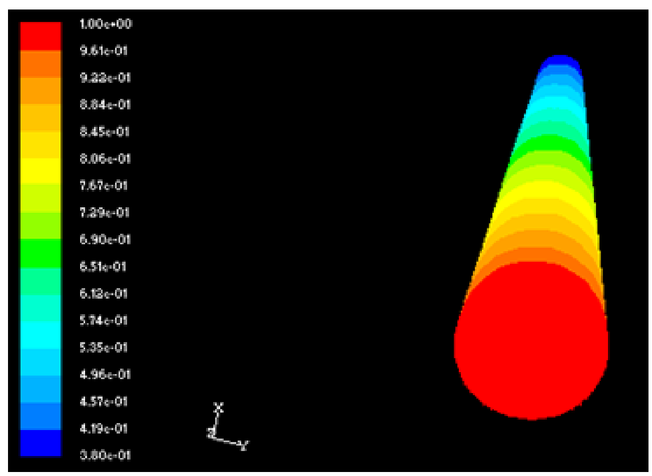


**Fig-5:** Gas-oil mass fraction along the riser height

## 3. CONCLUSION

A model of FCC riser having two-phase flow (gas-solid) and a four lump kinetic scheme is simulated using the Eulerian-Eulerian multiphase CFD model. The results of the model showed increase in catalyst and gas velocities all along the riser height. The temperature profiles obtained for both the cases were on expected lines. For gas-solid flow with reaction model the gas phase velocity increased from 4.7 to 14.7 from riser inlet to outlet due to cracking of heavy gas oil to lighter products. The results predicted gas oil conversion 62%, gasoline yield 39%, light gases yield 20%, and coke yield 3%.

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